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#2010-045

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Abstract

This paper examines the role of the global institutional frameworks on the national processes of innovation diffusion. we focus on the influence of the Kyoto mechanisms on the diffusion of renewable energy technologies in the BRICS countries i.e. Brazil, China India, Russia and South Africa. Our preliminary analysis suggests that the Kyoto Mechanisms may support the diffusion of some simple, low cost and mature technologies which are already diffused in the host countries, rather than the diffusion of new renewable energy technologies. This observation raises questions about the extent to which the Kyoto Mechanisms at its present state create major incentives for the diffusion of new renewable energy technologies in the BRICS, in the absence of a indigenous technological efforts and capabilities in new renewable technologies and national policy initiatives to attract and leverage the implementation of Kyoto Mechanism projects to support technology diffusion. We analyse these issues theoretically as well as empirically making use of national aggregated data from the World Development Indicators, the International Energy Agency, the United Nations Framework Convention on Climate Change and secondary sources.

JEL: O33, O19 , O13
Keywords: technology diffusion; renewable energy; global institutions; BRICS, Kyoto mechanisms

UNU-MERIT Working Papers

ISSN 1871-9872

Maastricht Economic and social Research and training centre on Innovation and Technology, UNU-MERIT

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1. Introduction

The industrialisation of developing countries and fast growth of emerging economies poses a fundamental question for policymakers and researchers working on development, innovation and global environmental sustainability. The question is whether the industrial, economic and social transformation of developing and emerging countries will follow conventional trajectories intensive in greenhouse gases emissions or manage to strive towards more environmentally sustainable growth pathways. The catching up process of the Newly Industrialised Countries (NICs) has been characterized by intense technological learning centred initially on the adoption, imitation, and adaptation of the technologies and industrial practices of developed countries (e.g. Hobday, 1995; Kim, 1998). In that context, environmental sustainability concerns have often been left outside the economic development argument. This neglect has been considered as a necessary initial cost before the 'take off' to full industrialization status (O'Conner, 1996). Such a 'grow now, clean later' development path (O'Conner, 1996) was supposed to follow the Environmental Kuznet curve that shows a worsening of environmental indicators until developing countries reach a certain level of economic development (i.e. GDP per capita), which is then followed by an improvement in environmental performance (World Bank, 2003).

However, the viability of pursuing such an approach has now been put in question by growing environmental deterioration and concerns about the global impact of climate change. It has become evident that global cooperation is necessary, especially among developed and developing countries, to deal collectively with climate change. This awareness has led to the establishment of several global institutions embodied in international agreements such as the Kyoto Protocol.

The Kyoto Protocol is a key international institutional framework requiring countries to limit or reduce their greenhouse gas emissions[1], but also expected to create mechanisms to support the transfer, adoption and diffusion of low carbon technologies to developing and transition countries in order to carry out emissions reductions. The Kyoto Protocol and its mechanisms – the Joint Implementation (JI), the Clean Development Mechanism (CDM) and Carbon Trading Scheme –

[1] Greenhouse gases stand for the gases specified in Appendix A to the Kyoto Protocol, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), partially halogenated hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6).

created a framework, based on market mechanisms and collaborations among stakeholders of different countries, to support signatory countries to meet the goal of limiting or reducing emissions. But adadditionally, it is an explicit objective of the Kyoto Protocol to foster the diffusion and adoption of greenhouse gases-reducing technologies as a subsidiary mean to cut greenhouse gases emissions in developing countries and transition countries respectively thus contributing to sustainable development. As stated by the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Mechanisms are also expected “to stimulate sustainable development through technology transfer and investment“…“in techniques that can help increase resilience to the impacts of climate change“, as means to attain emission reductions, also encouraging “the involvement of the private sector and developing countries on the cost-effective reduction of emissions“ (UNFCCC, 2010). In this context, it is expected that tradable permit regimes provide incentives for firms to implement cost-effective actions to reduce emissions adopting environmentally sound technologies in the process, as they are rewarded for cutting emissions with tradable carbon credits (UNFCCC, 2010).

Emission certification procedures in both JI and CDP projects follow similar procedures, but are based on different eligibility criteria. The CDM allows governments or private organisations from industrialised countries that have carbon emission reductions obligations under the UNFCCC (Annex 1 countries) to implement emission abatement projects in developing countries (non-Annex 1 countries) which have under the agreement no formal commitment to reduce emissions. Through CDM projects the participants can obtain certified emission reduction (CER) credits or carbon credits that can be traded and used by industrialised countries to comply with their reduction obligations. The arrangement has two overarching objectives: to reduce GHG emissions and to foster sustainable development in developing countries. The JI mechanism allows the joint carrying out of emissions reduction projects by two countries that belong to the UNFCCC (Annex I states). Thirty-three countries are eligible to participate in JI mechanisms including most of the developed countries and former URSS countries (UNFCCC, 2009). JI projects normally involve sellers of Emission Reduction Units (ERUs) from Russia and Eastern Europe and buyers from countries in Western Europe which have more stringent emission reduction obligations (Hepburn, 2007). The JI allows a country to claim credit for emission reduction arising from investment in other industrialised countries, which result in a transfer of equivalent ERUs between the Annex I countries. Under this international environmental institutional framework, Russia is eligible for hosting JI projects, while Brazil, China, India and South Africa are eligible for hosting CDM projects. Thus, the BRICS countries do not have the same status under the Kyoto Mechanisms.

The CDM and JI mechanisms started to be implemented slowly after the 2001 Marrakesh Accords, with the first projects entering the pipeline from 2004 onwards, almost a decade after the launch of the Kyoto Protocol in 1997 (UNFCCC, 2009; CDM, 2010). Much effort has been carried out to examine the impact of these mechanisms in terms of creating incentives for emission reductions and sustainability (Klepper and Peterson, 2006; Dechezlepetre et al., 2008). However, we still need to know more about how global institutional frameworks, specially the Kyoto Protocol and its mechanisms have influenced the diffusion of environmentally sound energy technologies. This is relevant because a major effort is being put in place to devise and implement global environmental regimes in the expectation that this will lead to desired changes in the behaviour of individual countries and their socio-economic systems. But until now, we simply do not know enough about the effectiveness of those demand-pull measures in attaining such expectations in shaping the pace and the direction of technology diffusion, especially of renewable energy technologies.

A large body of understanding about the dynamics of diffusion and the factors that influence these processes has already been accumulated (e.g. Rogers, 1995; Geroski, 2000). Yet, in terms of the role of policies and broad institutional frameworks on diffusion, the focus has been on the nationally designed policies. Less attention has been given to how international institutional frameworks and policies drive diffusion processes in a given economy. Moreover, empirical evidence on the diffusion of renewable energy technologies in emerging economies is still necessary. In particular the BRICS countries with their accelerated economic growth and associated environmental burdens, are at the forefront of the challenge in forging new pathways towards sustainable development. Yet, studies of the diffusion of renewable technologies driving the emergence of renewable energy innovation systems and the factors influencing the process in those countries are still sparse. In the absence of such evidence, the differences and commonalities in the diffusion of renewable technologies in industrialising as contrasted to industrialised countries can only be speculated. This provides a limited information base to underpin the definition of policy measures to support the diffusion renewable energy sources in those countries.

Building empirical evidence about the workings of global institutions and how they relate to the diffusion of more sustainable technologies represents a step in this direction. With that in mind, we aim to address in this study the following research question: What has been the role of the global environmental institutional framework on the diffusion of renewable energy technologies in the BRICS countries?

Drawing on the literatures on technology diffusion and global institutions we analyse the diffusion of renewable energy technologies in the BRICS countries. In particular, we examine what has been the influence the global institutional framework, specifically the Clean Development Mechanism (CDM) and Joint Implementation (JI) mechanism on the diffusion of the renewable energy technologies in those countries. We also examine this issue using data from the UNFCCC on CDM and JI projects in the pipeline, series data from 1987 to 2005 on energy use, as well as social, economic, technological characteristics of these countries collected from the World Bank Indicators and the International Energy Agency.

Our preliminary analysis suggests that global institutional frameworks providing market-based incentives, such as the CDM and the JI, may support the diffusion of simple, mature, low cost technologies, but not the investment in new renewable energy technologies or the diffusion of more complex and advanced renewable technologies. Consequently, this paper raises questions about the effectiveness of the Kyoto Mechanisms in creating major incentives for the national efforts in the diffusion and use of new renewable energy technologies in the BRICS. In light of these findings and the technological and market contexts of the diffusion of renewable energy technologies, we discuss the possibility of this international voluntary framework to trap and lock-in developing and industrialised countries into lower technologies. In particular, we raise questions about the extent to which the present form of the Kyoto Mechanisms create sufficient incentives for technology diffusion in the absence of strong national policies in developing and industrialised countries to draw technology-oriented benefits from the scheme, as well as in investments in scientific and technological capabilities. In this context, the international market-based voluntary mechanism alone may lead to inefficient and non-sustainable energy systems, as well as to increased economic and resources inequalities across countries.

The paper is organised as follows. In Section 2, we propose a conceptual framework to analyse the diffusion of new renewable and environmentally sound technologies in emerging economies, and the influence of the global institutional framework in shaping the process.

Section 3 describes the method and data sources. Section 4 presents the empirical evidence, and Section 5 concludes the paper.

2. Conceptual framework: the diffusion of new technologies in emerging economies and the role of international institutional frameworks

This section introduces the conceptual framework guiding the analysis of the diffusion of renewable technologies in the BRICS countries. Section 2.1 addresses the diffusion of new technologies. Section 2.2 examines the nature of the incentives created by international institutional frameworks.

2.1 The diffusion of technologies

We understand diffusion, based on Rogers (1995:5) as the process involved in the transmission of new technological knowledge via given communication and commercialisation channels through time among the integrants of a socio-economic system. Ultimately, diffusion corresponds to the summative outcome of innumerable decision-making processes by potential adopters shaped by trade offs between the advantages of the new technology to be adopted as compared to the involved costs, all that in a context of high uncertainty and incomplete information (Hall and Khahn, 2003:1). The heterogeneously paced diffusion of new technologies in an economy and the growth of industrial activities centred on these technologies changes the industrial structure, with some sectors declining, as new ones emerge (Metcalfe, 2001; Metcalfe and Ramlogan, 2005). Furthermore, the diffusion of new and more sustainable technologies may lead to the replacement, at least partial, of less sustainable variants.

The processes of decision-making to adopt innovations as well as the performance of the technology following adoption, and consequently the diffusion rates and patterns, may be conceptualised as being affected by supply and demand factors (Najmabadi and Lall, 1995; Goldman et al., 1997; Teubal, 1997). The demand factors include, for instance, the characteristics of potential users of technology that influence their expectations about the costs and benefits incurring when adopting the new technology. The supply factors encompass the characteristics of the new technology and of competing technologies, the incentives produced by suppliers of other related innovative resources and the technical networks of organisations. Policies and institutions may affect both demand and supply sides. In Figure 1, we sketch the main factors that may affect the level and pattern of diffusion of renewable energy technologies. We discuss them in detail below.

[Insert Figure 1 about here]

2.1.1 Demand factors

On the demand side the decision to adopt an innovation depends on the benefits users expect from the adoption as well as on the expected costs related to the search of information and the mastery of the innovation. Diversity in the relevant characteristics of individuals, organizations and countries often influence cost-benefit calculation of a new technology by adopters and consequently their decision to adopt or not a specific technology (Geroski, 2000; Dieperink et al., 2004).

A crucial of those characteristics which may impact on the diffusion of new technologies is the national technological capabilities to develop, imitate and adapt international technologies to the national productive activities. The technological capabilities of national users and producers of complementary or alternative technologies will influence the relative costs and benefits of the investment and adoption of a new technology.

Capabilities, skills and other characteristics of potential adopters also affect diffusion patterns because when a new technology is introduced, the benefits from its adoption may seem too risky and difficult to estimate a priori. Thus, early adopters may be somewhat different from subsequent users in terms of their technology capabilities, human resource skills, market competition and relations with customers. In particular, early-adopters are found to have a risk-taking attitude, as well as higher technical, organizational and managerial capabilities. This allows them to overcome both the technological and managerial problems and resistance that may rise from adopting a new, but not yet completely established technology (Metcalfe and Ramlogan, 2005; Egmond et al., 2006). As time passes and usage increases, more information on the performance of the new technology becomes available and technologies are improved. Consequently, the expectation about returns and risk involved with adoption change. The larger the initial base of early adopters, the faster might be the subsequent diffusion, because contrary to early adopters, the majority and laggards only adopt innovations after their legitimation, i.e. the acceptance and institutionalisation of the innovation (Abrahamson and Rosenkopf, 1993; Egmond, 2006.).

The legitimation process seems also to depend on capabilities and the cost of switching technologies, the size of the installed base of new users and expectations about market growth and the future evolution of technology (Geroski, 2000). Network externalities, stemming from previous investments in the technology and larger user base, may support the further diffusion of the 'chosen' technology, and even create lock in effects, irrespective of the inherent qualities of the technology and their alternatives (Nelson et al., 2004). Standardization is similar to the legitimation process because the adaptation to new standards would depend on the switching cost involved, the expectation of technology use based on the density of new users, the expectation about market growth and the future opportunity cost of adopting other technologies – or network externalities (David, 1985; Cabral, 2000). In the case of energy producing technologies, there are some technologies that have already been legitimised and others whose future acceptance remains uncertain (Aghion et al., 2009).

Also important seem to be the level of internationalisation of national business. The more internationalised are the national business activities, the more they will be exposed to mimetic sources towards the adoption of a managerial culture concerned with environmental protection (Abrahamson and Rosenkopf, 1993; Guller et al. 2002). At the same time, there might be a trade off between price and quality competition and the environmental impact of business activities (O'Conner, 1996; Roediger-Schluga, 2003).

Another factor affecting the level of diffusion of renewable energy producing technologies is related to the characteristics of the national natural endowments. The decision of energy producing firms and/or governments to invest or not in wind, solar or hydroelectrical energy sources depends on the natural endowments of their territory. Moreover, opportunity and sunk costs of using or replacing existing energy sources (e.g. fossil fuels) may discourage the use of renewable energy technologies. Given the relative high sunk costs of energy production plants, as well as the cost of learning and searching, the switching costs and opportunity costs of replacing existing technologies are considerable in energy producing technologies.

The level of economic and social development of countries, and consequently the level of environmental awareness, is also expected to affect the decision to adopt new energy production technologies. On the one hand, the greatest and fastest the economic and industrial development, the more emissions a country will produce. On the other hand, the more developed a country is, the higher the awareness of the population and policymakers of the environmental impact of energy producing activities (Aden et al., 1999).

2.1.2 Supply

Information on the technology as well as on alternative technologies is essential for the demand to calculate costs and benefits of technology adoption. In particular, the speed of usage of innovations is linked to the information available on methods, their use and knowledge of their function. The recognition of the importance of 'understanding' the innovation in the process of 'being persuaded to adopt', opens up various different potential explanatory variables, such as information about 'risks and uncertainty' and the benefits of adopting the technology and the learning capacity that lead to the difference in the speed of diffusion (Geroski, 2000; Rogers, 2002).

Additionally, diffusion can be influenced by other factors such as scientific and technological development leading to the evolution of the technology characteristics and the variety of technologies in the market. At each moment, users have several technologies to choose from. Despite the normal processes of standardization and legitimation observed during the diffusion process, technology diversity in terms of different technology vintages as well as of knowledge and resource bases associated to the used technologies are also expected (von Tunzelmann and Acha, 2005). This is particularly true for energy producing technologies where most developed countries continue to produce energy from fossil fuels and at the same time invest on production from renewable sources. This diversity may also be a deliberate policy choice aimed at improving/maintaining national energy security.

The evolution of the perceived characteristics of innovations in terms of relative advantage, compatibility, complexity, 'trialability' (i.e. the degree to which it may be experimented on a limited basis) and 'observability' of its results affect the cost-benefit calculations of users (Rogers, 1995). Moreover, services, marketing and the prices practised by suppliers of the technology have a direct impact on the cost of new technology acquisition, while their capabilities to redesign a new technology which exactly meets the needs of users can be decisive for a successful and rapid diffusion (Geroski, 2000).

In the case of energy producing technologies, performance, reliability, and sunk costs are technology factors that affect the decision of maintaining energy producing plants based on a diversified portfolio of technologies. Moreover, uncertainty on the evolution of energy technologies, which still depends greatly from further improvements based on scientific and technological developments, thus creating incentives for the maintenance of such a diversified portfolio.

Competition (among users, among technologies and among producers) may have different effects on diffusion depending upon the stages of innovation. For instance, at an earlier phase of innovation, competition would promote variety of technologies. However, as the technology matures, certain technologies will be 'legitimized' and diffused. Through legitimation and competition, the variety of knowledge/innovation in a particular market and/or social setting is limited (Cabral, 2000; Geroski, 2000).

Finally, there are other actors besides technology users and producers that may influence the relative cost and profitability of the adoption of innovation, such as opinion leaders and suppliers of other innovations. The professionals in a technical field who support firms to engage in the adoption of innovations may also affect the cost–benefit calculations of firms and facilitate the flow of information about the new technology (Valente, 1996). In addition, Rogers (1995) acknowledges that 'opinion leaders' (i.e. experts, consultants, technical organizations, technological and professional institutes), who are influential members of the social system to which they belong, also influence the adoption decision. 'Opinion leaders' might be mostly important in a collective and authority decision-making process.

2.1.3 Demand and supply

National institutional frameworks, in general, and public policies, in particular, can support innovation diffusion by supporting simultaneously demand and supply. They can support the provision and dissemination of information about the new technology, provide subsidies to foster the intake of the technology in the socio-economical system, affect users' evaluation of costs and benefits of technology adoption, encourage the building up of various types of human capital or stimulate the emergence of innovative inputs markets and new technologies (Justman and Teubal, 1996; Teubal and Andersen, 2000; Hall and Khan, 2003).

Some innovations may involve an 'optional' decision to adopt taken by individuals, others a 'collective' decision taken by consensus among members of a system, and still others an 'authority' decision taken by relatively few individuals who have power status or technical expertise (Rogers, 1995). In each type of situation, the diffusion process has different characteristics. In the case of energy producing technologies, it may involve a mix of all those decision-making situations, depending on the type of technology (e.g. solar panels, hydropower), as well as depending on specific legal, institutional and corporate setting of each country (e.g. national energy companies being private or public organizations).

The examination of the influence of public policies on diffusions of renewable energy technologies has mostly focused on the impact of policies designed by national governments (Aden et al., 1999; Blackman and Sisto, 2006; Garcia et al., 2007). However, policy frameworks have increasingly a supranational dimension. This raises questions about the impact of that specific policy dimension, namely the global institutional framework on the technology diffusion process.

2.2 Incentives in global institutional frameworks

A marked increase in the density of the institutional framework which functions at the international level has been observed over the last decade in particular in the realm of environmental and economic arenas (Young, 2002:8). Multilateral international institutions may be particularly relevant in dealing with global environmental sustainability because the solution for global environmental problems requires collective action among various countries to change the use of natural and environmental resources towards sustainable pathways (Lipsey 1997; Held et al., 1999). Consequently, policy-makers and several authors stress the positive impact of global institutional frameworks, especially through collaborative multilateral agreements on the diffusion of social, ethical and environmental standards (Lipsey 1997; Held et al, 1999).

At a general level, the design of incentive structures of international institutions to address environmental concerns is driven by two alternative but not exclusive approaches, the logic of consequences and logic of appropriateness (Young, 2002; March and Olsen, 1998). The former is based on an utilitarian perspective of actors whose behaviour is determined by the way particular incentives shape their calculations of the costs and benefits of a given course of action. The latter, however, takes into consideration actors' sense of ownership and participation in decision-making underpinning the design of incentive structures and the perceived fairness and legitimacy of the restrictions and performance requirements.

Deriving from that, international institutional frameworks foster compliance with agreement objectives and try to influence behaviour towards desired aims through positive and negative incentives, as well as sunshine methods (Weiss and Jacobson, 1998). Positive incentives include financial and technical assistance including training and access to technological sources. Negative incentives involve sanctions, penalties and privilege withdraws. Finally, sunshine methods are centred on monitoring, inspection, and reporting. Normally, international policies rely on a combination of these three types of incentives. Their specific usefulness depends on different contexts and changes over time (Weiss and Jacobson, 1998).

International agreements in environmental related issues tend to use mainly market-based incentives rather than also regulatory or command-and-control incentives. On the one hand, the use of market-based incentives is expected to allow the integration of economic and environmental/social decision-making and consequently to be more cost-effective due to the lower monitoring costs. In addition, by allowing greater flexibility for compliance, they are expected to encourage more diverse and innovative responses. On the other hand, creating a new market of property rights involves regulation and enforcement; consequently, free-riding could only be significantly avoided with huge investments in adequate monitoring and regulation.[2]

Indeed, free riding is an expected behaviour in international multilateral agreements. In particular, the probability of a country to join international environmental agreements is expected to increase with the free-riding benefits they can obtain from other countries' compliance, and decreases in their own noncompliance costs (Espinola-Arredondo and Munoz-Garcia, 2009). The voluntary and international nature of the environmental multilateral agreements, together with the embryonic state of lay knowledge of environmental technologies, may add to their inability to control and avoid some type of free-riding.

Moreover, due to lack of means for full monitoring and asymmetry of information between users and developers of international institutional frameworks, especially those implemented through ill-defined market-incentives may also create perverse incentives (Akerlof, 1970; Orr, 1976). This is because national and local actors have incentives to look for and exploit gaps in the established settings. Consequently, continuous policy learning in both policy design and implementation is so important. If policy learning is a long and difficult process at the national level, this is even more complex when policy learning needs to take place at the international level, in particular, if the costs and benefits of ill-defined markets are asymmetrically distributed across countries or among stakeholders.

Furthermore, market-failure also exists in the new environmental markets. The level of market investment in the development of new renewable technologies, for which there is still high uncertainty about the evolution in performance, will be below the social optimum. Hence, these market-based mechanisms are expected to provide few incentives for the development and diffusion of technologies in early stages of their life cycle (i.e. technologies not yet legitimised). Although, scientific and technological development has generated a wide spectrum of environmentally sound energy technologies and variety is still growing, with some embryonic technologies already competing in the markets, the technological selection phase is still being

[2] Evidence from the national level application of 'market-based' and 'command and control' instruments in the UK shows that 'market-based' mechanisms led to worst performance as the oligopoly of incumbents restrict target fulfillment. The 'command and control' policy instruments instead created opportunities for smaller market players to entry in the market and compete against monopolistic and oligopolistic power of incumbents companies (Toke and Lauber, 2007).

decided in the markets. In other words the portfolio of renewable technologies to be used in the future is not defined yet.

3. Methodology and Data

Our empirical analysis is based on aggregated national data from the World Development Indicators and the International Energy Agency, and information on CDM and JI projects hosted by the BRICS collected from the UNFCCC databases (JI, 2009; CDM, 2009). We complemented that data with information derived from secondary sources including research papers and other academic publications, policy publications, trade press and news articles.

Drawing on those datasets, our analysis proceeded as follows. In the first step, we examined the measures of the level of diffusion of technologies based on renewable and fossil-based resources in the BRICS as well as in a group of developed countries in the period 1987-2005. We analysed the levels of use of renewable sources and of fossil fuels on total energy sources, as well as the share of hydroelectric electricity production. The aim of this analysis was to examine the gap between developed and developing countries on the use of renewable energy producing technologies.

In the second step, we examined the specific data from the CDM projects hosted by developing countries and JI projects implemented and hosted by the Kyoto signatory countries. We analysed the characteristics of the projects hosted by the BRICS countries, their technological focus and the main buyers involved in each country in order to answer to the following questions: Does the technological scope of projects differ across the BRICS countries? Or is the technological scope of projects similar across the BRICS countries? If the national characteristics, especially demand (but also of supply) matter for the diffusion of renewable energies, we would expect that the technological scope of projects across the BRICS countries are different, i.e. that each country attract specific renewable energy technologies. Is there specialization in the provision of technologies from the part of the buyers of these projects? In other words, are some developed countries specialized in buying emission reductions through the provision and implementation of specific technologies in developing countries? If these international mechanisms foster the diffusion and transfer of the best technologies, we would expect that specific developed countries are specialized in the provision of specific technologies, independently of the hosting country. If, instead, the Kyoto Mechanisms create only a short term incentive for the diffusion of mature, cheap, easily available technologies, we would expect that a small group of countries would be buying most of the emission reductions certificates through a number of projects based on available technologies easy to be implemented. To proceed with this investigation, we collected data on the number and budget of CDM and JI projects that each of the BRICS countries hosted, as well as the technology focus and the buyers of these projects and analysed it using descriptive statistics methods.

In the third and final step, we addressed empirically the discussion in Section 2, and illustrated in Figure 1, which highlighted the importance of demand and supply side factors as well as of the global institutional frameworks on the level of diffusion of renewable energy technologies. We analysed the existence of significant linear associations between each of these different factors and the level of diffusion of renewable energy technologies in the BRICS. This exercise will inform us only on the degree of dependence and association among the variables, but it cannot however inform us on the cause-effect relationship among them . For this purpose, we relied on national aggregated statistics to characterise the natural resources endowments, economic and social development, national technological capabilities, the internationalisation of national businesses, national policy capabilities/culture, and the level of exposition to international institutions.

The national use of fossil and renewable energy technologies is inherently related to the characteristics of the national natural endowments. Among the national natural supply of inputs that are expected to support positively the use of renewable energies, we took into consideration the internal freshwater sources, the share of forest on total land. Among the national natural supply of inputs discouraging the use of renewable energy technologies, we considered fuels as share of exports, and the share of land dedicated to agriculture. We also accounted for the size of the country, and the size and density of its population.

The level of environmental concern is expected to be highly correlated to the level of economic and social development of the country. Therefore, we accounted for the level and the growth rate of GDP per capita, health expenditures, literacy rate, expenditure per student in primary and secondary education, share of children economically-active, daily newspapers, number of users of the Internet, number of personal computers and vehicles per 1000 people, share of GDP in agriculture, industry and services. As seen in section 2, the greater and quicker economic and industrial development, the more emissions the country is expected to produce, but after a certain level of development, environmental concerns may diffuse across the population and among policymakers.

To account for the internationalisation of national businesses, we included the share of ISO-certified firms, the share of FDI on GDP, the share of royalties on GDP paid abroad, and trademarks per 1000 people by residents and non-residents. Other factor crucial for the diffusion of new technologies is the national technological capabilities to imitate and adapt international technologies to the national productive activities. Therefore, we included the share of high-technology exports, the share of R&D expenses on GDP, expenditure per student in tertiary education, the share of royalties received on GDP, the number of scientific papers and patents per 1000 people, the number of researchers and technicians in R&D.

National policies also play a role in creating national incentives for the diffusion of renewable energy technologies. National policy capabilities to design and launch these policies may be highly dependent on the national natural endowments as well as on the level of national commitment to comply with global institutional frameworks and on the level of national involvement in international cooperation for technology transfer. Hence, it would be very difficult to identify whether national policies were designed and partly implemented to comply with international frameworks or to try to establish cleaner energy systems. Moreover, policy capabilities seem to co-evolve with the national levels of economic and social development, technological capabilities and participation on global markets (Teubal and Andersen, 2000). Therefore, for the purpose of this analysis, we included variables only to account for the national policy culture and capabilities, i.e. military expenses, natural protected areas and investment in energy with private parts as percentage of GDP.

Finally, our central concern in the paper is the relationship between the evolving global environmental institutional framework, specifically the Kyoto Mechanisms and the diffusion of cleaner renewable energy technologies. To account for the level of influence of international institutional frameworks, we included the number of CDM and JI projects and the level of CERs and ERUs derived from projects hosted in each country in each year.

Using this information we computed the Spearman's correlation coefficients of each of the given variables with proxies for the level of diffusion of renewable energy technologies. These proxies included the share renewable sources on total energy sources, the share of renewable combustibles on the total national energy production and consumption, the percentage of fossil energy on the total energy consumption, and GDP per unit of energy use.

4. Empirical analysis

In this section, we analyse the role of the global environmental institutions on the level of diffusion of renewable energy in the BRICS countries. First, the diffusion of renewable and fossil energy technologies is analysed from 1987 to 2005 and compared with the evolution of these indicators in some developed countries. Second, the characteristics of the projects carried out in BRICS under the JI and CDM frameworks are analysed. Third, the significant linear associations between the level of reliance on renewable energy and the several factors proposed by the innovation diffusion theory as affecting this level, including projects undertaken under the Kyoto mechanism are analysed.

4.1. The diffusion of renewable energy technologies in the BRICS countries

We start by examining the share of renewable sources on total energy sources (Table 1). In 2006, Austria presented the highest level of reliance on renewable sources; 69% of the total energy sources were renewable. Brazil and Sweden followed with a bit less than 50%, India with 40% and Switzerland with 34% of total energy sources being renewable. The greatest efforts on the use of renewable sources have been made by Germany, followed by the UK, and the Netherlands. France and Denmark instead did not show a significant increase on the diffusion of renewable energy sources. This data stresses the prevailing heterogeneity on the intensity and pattern of the renewable energy uses across the BRICS as much as across developed countries. The major difference between the BRICS countries and developed countries on the reliance on renewable energy sources refers to the evolution of the diffusion of renewable sources. During 1990s and early 2000s, in the BRICS countries the intensity of reliance has been maintained or decreased, while in the group of developed countries analysed this intensity has increased or been maintained.

[Insert Table 1 about here]

In order to throw some light on the composition of the renewable energy sources used by the BRICS, we start by examining in detail the level of use of combustible renewable on total energy. Graph 3 shows the share of combustible renewables and waste, which comprise solid biomass, liquid biomass, biogas, industrial waste, and municipal waste measured on total energy use in the BRICS countries and in a group of developed countries, during the period 1987 to 2004.

[Insert Graph 1 about here]

During the period of analysis, India, Brazil and China show a higher level of use of renewable combustibles of as compared to developed countries considered. The UK, Japan and Russia have the lowest level of the use of these energy technologies. India displayed the highest level of use of combustible renewables and waste on total energy, despite experiencing a great decrease in these levels. In the 1990s, circa of 40% of the total energy used in India was renewable combustible, while in the 2000s this ratio decreased to 30%. This high share is due to India's reliance on non-commercial energy sources in rural areas, including firewood, crop residue, and animal waste, whereas the decrease in the use of renewable combustibles is attributable to a replacement of traditional sources by more efficient commercial energy sources (India Energy Portal, 2010; KPMG, 2007). Similarly, in the 1990s, 30% and 20% of the energy used in Brazil and China respectively was renewable combustible; while in the 2000s it was about 25% in Brazil and 13% in China. The decrease observed in the use of renewable combustibles in India, China and Brazil is to an extent in line with previous observations which indicate that economic development leads first to a reduction in the use of traditional renewables and an increase in fossil fuels rather than an increase in the use of modern renewables (Goldemberg and Coelho, 2004; Arnold et al., 2006; van der Horst and Hovorka, 2009). In contrast, in Russia and South Africa, the levels of renewable combustibles on total energy consumption were however stable and significantly lower during the period of analysis, about 1% and 10% respectively.

However, to better understand those results, we limit now the analysis to modern biomass sources.. Modern biomass technologies are used as a commercial sources of energy and include transportation fuels (i.e. biofuels, biodiesels and biogasoline combustibles), electricity generation and heat production from agricultural inputs, forest residues and solid waste (Goldemberg and Coelho, 2004; Demirbas, 2009). These modern renewable combustibles were already produced and used in Brazil since the 1970s (Lemos, 2007). In 1990, biofuels, biodiesels and biogasoline combustibles represented 10% of the total energy production, from 2000 to 2004 their production decreased significantly, reaching only 5% of energy production in 2004, and from 2004 to 2006 it increased to 6% of total energy. China started the production of these combustibles in 2001. The other three BRICS did not produce any of these combustibles. During the 1990s, only Austria, France, Germany and the US used these combustibles, representing 0.1% of total energy sources. In 2006, in Germany these combustibles reached 3% of total energy sources. Thus, in Brazil, the large, but decreasing (less accentuated though than in India or China) use of renewable combustibles was also certainly due to modern commercial renewables. The small increase on the reliance of combustible renewables in Germany seems to reflect mainly efforts on the use of modern renewable sources.

We also examine the levels of reliance on hydropower for electricity production and contrast with the levels of reliance on fossil fuels. Graph 2 the share of electricity production from hydroelectric sources (% of total) and Graph 3 shows the share of electricity production from coal and oil sources (% of total) in the BRICS countries and a group of developed countries from 1987 to 2004.

[Insert Graph 2 and 3 about here]

Graph 2 and 3 show that more than 90% of electricity produced and used in South Africa is based on coal (and oil) sources, less than 1% on hydroelectric sources and no use of natural gas. In contrast, less than 6% of electricity production in Brazil uses coal or oil sources. Brazil relies significantly on hydroelectric sources for electricity production, although this reliance has decreased during the period of analysis, as the use of natural gas increased. In the early 1990s more than 90% of Brazilian electricity was produced from hydro sources, while in 2005, 82% of electricity was derived from hydroelectric sources. The use of natural gas for Brazilian electricity production started in the mid 1990s, and in the 2005 represented almost 5%. In the early 1990s, in China and India, 70% of electricity was produced from coal, and about 20% from hydroelectric sources. In India the share of electricity produced from coal has been maintained (70%) and from oil at 4%; whereas from hydroelectric sources the share decreased to about 13% and from natural gas it increased from less than 2% to 9%. In China reliance on coal has increased to almost 80%, while reliance on hydroelectric and on oil has decreased respectively to 15%, and to 3%. The use of natural gas in China has been maintained at less than 0.5% of electricity sources. About 45% of electricity production in Russia depends on natural gas; reliance on hydroelectric sources has increased from 15% to 18%; coal has increased from 15% to 17%, and oil has decreased from 10% to 3%. In sum, natural gas is the main input for electricity production in Russia, while coal is the main input for electricity production in South Africa, China and India, and hydropower in Brazil.

A few differences are found between BRICS and developed countries. Except for Brazil, the other analysed countries with the lowest levels of reliance on coal and oil, i.e. Switzerland, Sweden and France, rely extensively on nuclear sources, 40%, 50% and 70% respectively on total electricity produced. Reliance on nuclear technologies is low in the BRICS countries. In 2005, it was about 2-3% of the electricity produced in Brazil, China and India, 4% in South Africa and 15% in Russia. In contrast, among the developed countries analysed only Denmark and Austria do not rely on nuclear sources for electricity production; all the others rely on nuclear sources for at least 20-30% of their electricity production. Brazil is the country in which reliance on hydroelectric energy is the highest, followed by Austria, Switzerland and Sweden highlighting the importance of hydroelectric sources in the energy mix of the countries which display the highest share of renewable energy on total energy sources (see Table 1). In contrast, the Netherlands, Denmark, France, Germany, UK and South Africa are the countries in which hydroelectric technologies are less diffused.

Finally, we examine data on the world leaders in the existing modern renewable energy capacity and production in 2006 and 2008. Table 2 below provides information on the five top countries in terms of their capacity and annual production of renewable energy. Information has been extracted from the REN21 (2007, 2009). This data shows that three BRICS countries are among the five top countries in the level of energy capacity produced from different modern renewable sources. The main difference between developed countries and the BRICS on installed capacity based on modern renewables refer to the primacy of developed countries on establishing capacity to use solar photovoltaic sources (grid-connected). Both developed and developing countries are involved in the production of first generation biofuels, which are not produced using sustainable processes and they are unlikely to promote sustainable development (de Gorter and Just, 2009; Demirbas, 2009; Ewing and Msangi, 2009, Kuchler, 2010). Additionally, as some authors have pointed out the biofuel blending authorized in several countries including Brazil, the Europe and US encourage rather than discourage the use of fossil fuels by lowering the price of the blended gasoline with ethanol (de Gorter and Just, 2009; Ewing and Msangi, 2009).

[Insert Table 2 about here]

Overall, this analysis suggests that heterogeneity exists within the BRICS as well as within developed countries in terms of reliance on different energy sources, as well on the extension and composition of their renewable energy sources portfolio. The use of hydroelectric, nuclear, natural gas and coal and oil sources for production of electricity, as well as the use of renewable sources is uneven across countries. In particular, the national portfolios of energy producing technologies seem particularly related to their national natural endowments and technological capabilities. The group of developed countries analysed use more intensively nuclear technologies and to a lesser extent natural gas as source for electricity.

Although, the intensity of reliance on renewable sources is uneven across countries, no major divide has been found between the BRICS and the group of developed countries analysed. In 2006, Austria has the highest level of reliance on renewable sources, followed by Brazil and Sweden, India and Switzerland. However, differences are found on the pattern of diffusion of renewable sources since the early 1990s, as most BRICS decreased their reliance on renewable sources and most of the developed countries analysed increased their reliance, reflecting mostly likely a reduced use of traditional renewables in the BRICS and an increased use of modern renewable in developed countries. For instance, Germany made a major stride on the use of renewable energies during the 1990s and 2000s based on modern renewables such as solar, wind and commercial biomass energy.

Concerning the portfolio of renewable sources, heterogeneity seems to prevail. For example, modern biofuels seem especially important to Brazil, but in the late 2000s, Germany and the US also became leaders in their production of biofuels. Biofuels are also increasingly important to China. Wind power became of important for India and China, while small hydro became relevant for China and Brazil. The major difference between the BRICS and developed countries seems to be related to the reliance on Solar PV sources that is higher in advanced countries.

4.2. Characteristics of CDM and JI projects in the BRICS countries

After having analysed the national aggregate data on the level of diffusion of renewable energy producing technologies, and of renewable sources on total energy production, we focus now on the analysis of the characteristics of the projects for emission reductions in which the BRICS countries are involved under the Kyoto Protocol. As seen in section 2.3, under the Kyoto Protokol, Russia is eligible for hosting JI projects, but not CDM projects. Brazil, China, India and South Africa are eligible for hosting CDM projects.

4.2.1 The number of JI and CDM projects in the BRICS Countries

In May 2009, there were 204 ***Joint Implementation projects*** in the pipeline. 102 of these 204 projects (48%) were implemented in Russia, 34 (16%) Ukraine, 59 (28%) in other Eastern European countries, 7 (3%) in Germany, 6 (3%) in New Zeeland, and 1 in France (CDM, 2009). While 48% of JI projects were implemented in Russia, 61% of the expected emission reductions in 2012 resulting from all the JI projects are expected to benefit Russia.

In May 2009, there were 4733 ***Clean Development Mechanism projects*** in the pipeline; 2935 in the process of validation, 1596 already registered (500 of which have already had issuance of CERs), and 202 in the registration process. 60% of these CDM projects in the pipeline aim at reducing between 10 and 100Kt CO_2 per year; 25% aim at reducing between 100 and 500Kt CO_2 per year, 10% aim at less that 10 KT CO_2 emission reduction per year. Almost 80% of CDM projects are hosted in Asian countries, 18% in Latin American (LA) countries and 2% in African countries. However, the greatest carbon emissions reductions per capita by 2012 are expected in LA.

Table 3 shows the total number of CDM projects issued, registered and in validation in 2009 in the BRICS countries. China is expected to benefit from more than half of the total registered or in-the-pipeline CDM projects, both in terms of number of projects and CERs. China is followed by India and Brazil. South Africa instead has a lower position in the ranking of countries benefiting from CERs, benefiting less than 1% of the CERs anticipated on the total number of CDM projects registered or in the pipeline. The tendency seems to be that CDM projects concentrate even more in China, as the share of issued projects hosted by China is lower than the share of projects in the pipeline (including also projects that are still to be validated and registered).

[Insert Table 3 about here]

Table 4 summarises the number of JI and CDM projects that have been implemented, validated or are still to be validated which are hosted by each of the BRICS countries. It is evident that the BRICS countries host about 70% of the CDM and JI projects.

[Insert Table 4 about here]

4.2.2 The technological scope of JI and CDM projects in the BRICS countries

Table 5 below provides details on the technological and sectoral scope of the total JI projects in the pipeline as well as of JI projects hosted in Russia. When, comparing the technological and sectoral scope of projects hosted in Russia with the total JI projects, we find one main difference. Projects hosted in Russia address more often issues of energy efficiency in manufacturing rather than on the supply side.

[Insert Table 5 about here]

Table 6 provides information on the sectoral and technological scope of CDM projects in the pipeline in Brazil, China, India and South Africa (columns 1 to 4), as well as of all the CDM projects issued, registered and in the pipeline independently of their host country (columns 5 to 7). Generally, a tendency towards the diffusion of hydro and biogas technologies seems to be observed in the CDM projects (Table 6 columns 5 to 7), as the share of CDM projects in the pipeline addressing these technologies is higher than the share of CDM projects issued or registered. In contrast, a decreasing tendency may be spotted towards the diffusion biomass or energy efficiency in agriculture.

[Insert Table 6 about here]

Examining the technological scope of CDM projects hosted by the BRICS and comparing this profile with that of all CDM projects, some national specificities are found:

- Projects hosted in Brazil concentrate on biomass, hydropower, energy efficiency in agriculture and landfill gas. Brazil observes a large relative advantage in attracting CDM projects in agriculture efficiency and biomass, and a large relative disadvantage in CDM on wind technologies, when compared with total CDM projects on pipeline.
- Projects hosted in China focus mainly on hydropower, wind, energy efficiency of energy production and coal mine. China observes a great relative advantage in attracting projects on coal mine, and some advantage in hydropower and energy efficiency of energy production. Instead, it experiences a great relative disadvantage in CDM projects in biomass and agriculture efficiency, compared with total CDM projects on pipeline.
- Projects hosted by India focus on biomass, wind, energy efficiency in industry (especially in cement industry), and energy efficiency of energy production. India relative advantages are observed in energy efficiency of energy production, and some advantage in CDM projects on biomass and wind technologies. Instead, India observes a relative disadvantage in energy efficiency in agriculture, hydropower and landfill gas.
- Projects hosted by South Africa focus on landfill gas, biogas, N2O and fuel switch. South Africa observes a great relative advantage in attracting projects in coal mining, fuel switch,

and landfill gas, i.e. on attracting projects in areas on which there are very few CDM projects.

Overall, this analysis revealed, except for biomass and landfill gas, that JI and CDM projects have different technological focus. 80% of JI projects focus on fugitive emissions from fuels, energy efficiency in the supply side, biomass energy, fossil fuel switch, landfill gas and N2O. While 80% of CDM projects focus on hydro energy, biomass energy, wind, energy efficiency own generation, landfill gas, biogas, agriculture, and energy efficiency in industry. Solar sources represent less than 1% of total CDM projects.

4.2.3 Buyers of JI and CDM projects

We focus now on the examination of the major buyers of CDM and JI projects in the pipeline in 2009 hosted by the BRICS countries (Table 7). Concerning ***Joint Implementation projects***, the major buyers are the Netherlands, the UK, followed by Austria, Denmark and Japan. These five countries are responsible for more than half of the total JI projects (JI, 2009). When analysing the countries involved in JI projects hosted by Russia, we find that 25% of the Russia projects were proposed by the UK, 9% by Denmark, 5% Austria, 5% Netherlands and 4% Sweden. The remaining projects are attributed to either national or international organisations (e.g. World Bank).

Concerning the ***Clean Development Mechanism projects***, the major buyers are the UK, Switzerland, the Netherlands and Japan. These four countries are involved in about 66% of projects hosted in Brazil, 53% of projects hosted by South Africa and China, and 23% of projects hosted by India. As circa 75% of projects hosted in India were proposed by international or national organisations, this group of buyers are almost responsible for the total of the projects promoted by private or public organizations from developed countries. Germany and Sweden are important buyers (16%) of the projects hosted in China. Switzerland does not participate alone in projects hosted in China.

[Insert Table 7 about here]

Finally, we examine the level of specialization of buyers across technologies. Table 8 provides information on the participation of Japan, Netherlands, Switzerland and the UK in CDM projects with some of most common technological scopes of CDM in pipeline in 2009, hosted by the BRICS. Four main surprising results emerge. The first finding relates to the massive participation of Japan, the Netherlands and the UK in CDM projects involving hydroelectric technologies, when especially the UK, make such a reduced use of them at home.

[Insert Table 8 about here]

The second finding refers to the strong focus of CDM projects technological areas in which the host countries already have considerable production capacity and technologies that are already locally available and widely diffused. n; Brazil hosts relatively more CDM projects using biomass energy technologies than average. In Section 4.1, we have seen that these technologies are much more diffused in the BRICS than in developed countries. In particular, the UK and the Netherlands started using renewable and waste combustible technologies in the 1990s, while Brazil was leading on the intensity of use of these technologies, representing 10% of total energy used (IEA, 2009; REN21, 2007, 2009). Similarly, India seems to attract a great share of CDM using wind technologies, when Indian technological capabilities in wind technologies have been recognised (Lewis and Wiser, 2007).

The third relevant result is that the participation of buyers in specific technologies differs according to the host country. In other words, buyers are not specialised into a specific technological scope. For example, Switzerland participates in no hydro project in China, and only 1% of its projects hosted in India are on hydro technologies, while 15% of its projects hosted in Brazil are in hydro technologies. 27% of Japanese projects hosted by Brazil are in biomass energy, but only 1% of projects hosted by China refer to the use of biomass energy. Japan, Netherlands, Switzerland and the UK participate in 74% of wind projects in China, but only in 27% of wind energy projects in Brazil. None of these buyers countries has a project on energy efficiency own generation hosted in Brazil, but they participate in 72% of projects with the same scope in China. Finally, it is surprising that only four developed countries dominate the demand for emission reduction certificates through implementation of CDM projects using a variety of technologies.

4.3 The CDM and JI and the level of diffusion of renewable energy technologies in the BRICS

In this section we address empirically the issues raised previously in Sections 2 and 3, and illustrated in figure 1, which has highlighted the importance of demand and supply side factors as well as of global institutional frameworks on the process of technology diffusion. We analyse the existence of significant linear associations between each of these different factors and the level of diffusion of renewable energy technologies in the BRICS. Table 8 provides the summary of the Spearman's correlation analysis performed with data from 1987 to 2005 for the BRICS, except for data on the CDM projects for which there were only observations relative to the last three years of the time series.

[Insert Table 8 about here]

Results suggest that national natural endowments create diverse incentives to the use of specific energy technologies. National endowments in fossil fuels are associated with greater levels of emissions and reduced levels of adoption of renewable energy technologies, contrary to endowments in internal freshwater and forest resources. Size and density of national population are positively correlated with the diffusion of renewable energy sources.

The results also suggest that during the 1990s, in the BRICS countries, economic development and industrialisation rely on fossil fuels. Similarly, the levels of internationalisation of national business activities may not favour the development of a managerial attitude more environmentally friendly in the BRICS countries, suggesting that environmental concerns are not yet truly a management concern in the global business environment.

The national technological capabilities of the BRICS countries are negatively associated with the development of sustainable technologies, but instead they are positively correlated with efficient reliance on fossil fuels. The national R&D activities in the BRICS seem still to be focused on advances related to energy-intensive industries/technologies. Only higher education and developed service sectors seem to enhance diffusion of renewable technologies.

As expected, in an economy in which national policy culture is concerned with protecting natural areas, the diffusion of renewable energy technologies may be quicker. Contrarily, military focus may divert attention from environmental concerns, as suggested by the negative and significant correlation coefficient with the level of renewable on total energy sources and with is positive and significant correlation coefficient with the level of fossil fuels on total consumption.

Finally, we also examined the relationship between the number of CDM and JI projects and the diffusion of renewable energy technologies. The results indicate that the number of CDM and JI projects are positively correlated with an increase of output per unit of energy use, and consequently to more efficient economic use of fuel energy. In contrast, the number of CDM and JI projects is not associated with the use of renewable sources of energy. No significant correlation coefficient is found with the variable CER of registered CDM projects.

Although the short time series available does not allow to draw conclusive observations about the relationship between the Kyoto Mechanisms and the diffusion of renewable technologies, it does raises some interesting questions. A first question is the extent to which the Kyoto Mechanisms in their present form create sufficient incentives for technology diffusion and other technological objectives which have been stated as one of the goals of the mechanisms. As indicated by the findings presented in Sections 4.3.2 and 4.3.3 CDM and JI projects have tended to concentrate on technologies that have been already widely used in host countries. Indeed, CDM and JI buyers are not specialised in given technologies and tend to invest in projects which rely on technologies that are already locally available and widely diffused. Locally available technologies and associated know-how allow buyers to undertake low opportunity cost projects ("low hanging fruit" projects) that are quicker to be implemented and permit investors from developed countries and at times from emerging countries themselves to acquire low cost and easy emissions units and make profit on trading those CERs. This may be due to perverse incentives emerging from the Kyoto Mechanisms because emission cuts from 'low hanging fruit' projects are priced the same as from more complex costly projects and involve less burdensome bureaucracy. 'Low hanging fruit' projects may involve local simple technologies such as first generation biofuels, conventional biomass, and hydropower that are already widespread locally or only the adoption of a new equipment (hardware transfers) which associated to the small overall number of CDM projects fail to make a substantial impact on the diffusion of more sustainable variants of renewable technologies such as solar cells, wind power, second generation biofuels, etc. These observations are also confirmed by existing empirical evidence also show that most CDM projects rely on local technologies and less than 20% rely only on foreign technologies (Doranova, 2009; Dechezlepretre et al., 2008). As a consequence, CDM projects may reinforce patterns of specialization of emerging countries to some extent in low variants technological paths, such as first generation biofuels in Brazil or large hydro in China may lead to the perverse outcome of locking in emerging countries in less sustainable variants of technologies.

A second related question is the extent to which endogenous technological capabilities and efforts in advancing and installing capacity to use a specific renewable technology determine the level of attraction and benefit of projects implemented under the Kyoto Mechanisms. The portfolio of projects, implemented under the Kyoto mechanisms, hosted by each of the BRICS countries seem to be different and closely related to the existing focus of specialisation of each country. For instance, Brazil has a strong advantage in attracting of biomass projects, while India, and to a lesser extent China in attracting wind projects at the same time that they already appear among the world leaders as the largest producers of energy based on these sources (Table 2). These observations suggest that national technological efforts and capabilities seem to be an important factor in attracting CDM projects. While the overall industrial technological development goes hand in hand with economic development and may lead to a stronger demand of fossil fuels (Arnold et al., 2006; van der Horst and Hovorka, 2009), the development of capabilities in using specific renewable technologies instead allow these countries to signal to carbon markets the potential for relatively cheaper CERs by relying on local capabilities and infrastructure (eventually ongoing projects). Indeed, contrary to CDM projects in sewage and landfill, CDM projects in wind, hydro, biomass seem to be tightly connected with the host characteristics (Schneider et al., 2010)

A third important question is the extent to which the creation of additional incentives for diffusion may also depend on the national implementation strategies of the Kyoto Mechanisms of different national governments through national policies. Countries have different policies objectives and use different policy instruments to implement international protocols. This diversity may lead to considerable variation in the functioning of the new created market-based incentives and widely different outcomes. In the case of CDM, national governments need to approve individual projects and are thus entitled to exert some influence in their implementation. Some countries such as China and South Korea include explicit requirements that CDM projects should include 'technology transfer' elements and as a result 88% of projects in South Korea and 75% in China include a degree of 'technology transfer' (Popp, 2008).[3] In contrast, India and Brazil do not include such requirements in CDM approval procedures and display lower number of projects including 'technology transfer' (Popp, 2008). In addition, different national environmental policies (e.g. environmental taxes, investment tax incentives, tradable permits, user charges and deposit refund systems) are also seen as one of the reasons for the non-functioning of the carbon market created by the Kyoto mechanisms. Only some countries regulate nationally environmental issues through marketable permits.

5. Conclusions

In this paper we analysed theoretically and empirically the role of the mechanisms of the Kyoto Protocol for emission reductions in the developed and developing world on the diffusion of renewable energy technologies in the BRICS countries i.e. Brazil, China, India, Russia and South Africa. For this purpose, we have relied on existing literature and on national aggregated data from the World Development Indicators and the International Energy Agency, as well as data from UNFCCC.

The energy data presented in Section 4.1 suggests that there is a great level of heterogeneity across the BRICS as well as across developed countries on the intensity and composition of their use of renewable sources for energy production. There is no apparent lagging behind of BRICS towards developed countries on the reliance of renewable sources (also when focusing only on modern renewable energy sources such as biofuels and wind energy). The major difference between developed and developing countries refers on the reliance on solar energy that is much more diffused among developed countries. Some differences are however found on the evolution of the diffusion of renewable sources, as since the early 1990s most BRICS decreased their reliance on renewable sources and most of the developed countries analysed increased their reliance, reflecting the reduction in reliance on some traditional renewables with economic development in the BRICS, as well as the heavy investment in modern renewable technologies in some developed countries.

[3] It is not clear thought what is included under technology transfer, if only equipment or disembodied knowledge.

In relation to the implementation of CDM and JI mechanism, despite the ideal objective of democratization in their application and diffusion of technologies to support sustainable development in developing and emerging countries, concentration seems to be the main characteristic of the Kyoto Mechanisms, CDM and JI. More than 70% of these projects are hosted by the BRICS countries, China concentrating almost 50% of the total number of projects. Similarly, concentration exists on the side of buyers of JI and CDM projects. Japan, the Netherlands, Switzerland and the UK are responsible for more than 50% of investments in CDM projects in the BRICS countries. Most of the main buyers of CDM and JI projects experience a low relative reliance on renewable sources (traditional and modern ones) than the large hosts of CDM projects.

Besides, a national specialisation in the attraction of projects with specific technological scope is identified, with the majority of projects in each country concentrating on mature technologies that are already diffused locally. Most projects hosted by Brazil employ biomass energy and hydropower technologies; hydropower and wind technologies are dominant in China; biomass and wind energy technologies in India; and energy efficiency technologies in manufacturing in Russia. Consequently, these findings confirm earlier observations that especially the CDM mechanism focuses on the use of local available existing technologies and capabilities (Doranova, 2009; Dechezlepretre et al., 2008).

The empirical analysis presented in section 4.3 suggests that the natural endowments of the country, higher education and the national policy culture are among the most important factors which may support the diffusion of renewable technologies. National economic and social development, the internationalisation of national business and national technological capabilities may instead support further reliance on fossils and hold back the diffusion of renewable technologies. These results based on the examination of the linear correlation coefficients need further research using different empirical methods.

Overall according to our observations based on existing energy data, CDM and JI data and secondary sources, the Kyoto collaborative mechanisms, seem to support the diffusion of low cost and mature technologies easy to be implemented through “low hanging fruit” projects, but not the diffusion of new renewable and cleaner technologies. These findings, though preliminary, raise important questions about the incentives being created by the Kyoto Mechanism to promote technologies that can support sustainable development.

First, the observations raise a question about the extent to which the Kyoto Mechanisms support investment and technology diffusion of more complex and dynamic renewable energy technologies. The Kyoto Mechanisms at present create mainly incentives to ‘low hanging fruit’ projects, in other words CDM projects aim at achieving the maximum of CERs or ERUs at the minimum cost, consequently their emphasis on the use of local technologies because those may be cheaper and quicker to be implemented. In this way the international voluntary framework may trap and lock-in developing countries and transition countries into lower variant technologies and the incentives to ‘low hanging fruit’ projects may also create a vicious cycle. Unless CDM and JI projects also involve flows of disembodied knowledge that goes beyond operating know-how and/or revenues from such projects are used to build engineering and design capabilities, it is questionable whether those companies will build capabilities to deal with high opportunity costs projects as the low cost ones become scarce. This will hinder further emission cuts that need to be implemented through ‘high hanging fruit’ projects and the diffusion of more complex cleaner technologies.

A second question emerging from the empirical observations is related to the role of endogenous technological efforts in shaping the level of attraction and the impact on technology diffusion of CDM and JI projects. The BRICS countries seem to attract projects in sectors and technologies in which they already have considerable production capacity and technological capabilities, which provide market signals about potentially cheap and easy carbon credits based on projects employing technologies already diffused locally.

A third final question the findings suggest is if the creation of incentives for the diffusion of renewable energy in emerging countries is dependent on the policy efforts of individual countries to develop appropriate implementation strategies that privilege objectives related to the diffusion of new cleaner energy technologies. A case in point is the performance of China in attracting and leveraging CDM projects which may reflect the national governmental effort to develop a policy structure that directs CDM support towards its owns priorities (by adding own national requirements) and that engages key governmental and private organizations to nurture from the CDM opportunity. A parallel could be made between the way Ireland managed to benefit and leverage from the European Structural funds (Sharp, 1998; Barry, 2000) and the way China seems to be managing in attracting and leveraging on CDM (contrary to many other countries, for example, South Africa) (Schroeder, 2009; Fay et.al., 2010). Thus, it seems that national benefit from international frameworks seems to require national policies to channel incentives to national priorities.

In order to illuminate these questions, several directions of further research can contribute to deepen understanding about the role of global institutional frameworks on technology diffusion. Further research would be needed to explore the impact of different types of international frameworks (i.e. frameworks based on regulation and sanctions, providing technical assistance or frameworks based on monitoring) on the development and diffusion of new technologies. Specifically on the impact of the Kyoto mechanisms, further research would be needed to understand their functioning and impact on the use, diffusion and generation of new renewable and cleaner in developing and transition countries. More understanding is needed about how projects are set up, the main objectives that are negotiated between the participating parties, and the critical elements/requirements for buyers to invest on projects. Also relevant is if projects are private buyer- or government-driven and whether and how CDM host countries have put institutional and corporate efforts in attracting and negotiating these projects.

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Figure 1. The factors affecting the diffusion of technologies

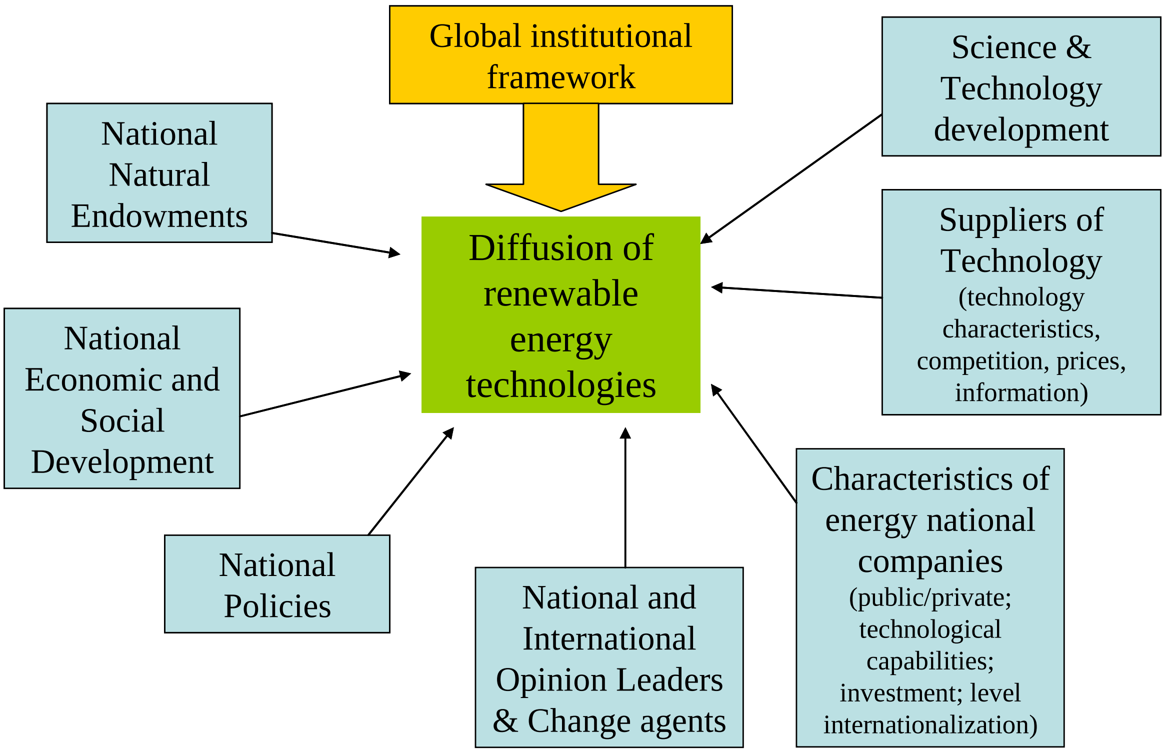


Table 1. Share of renewable sources on total energy sources in the BRICS countries

	1990	1995	1997	2000	2004	2006
Brazil	63%	61%	58%	49%	49%	48%
China	24%	21%	21%	22%	17%	15%
India	48%	44%	42%	43%	40%	39%
Russia	2%	2%	2%	2%	2%	2%
South Afr.	9%	9%	9%	9%	9%	9%
Austria	61%	67%	68%	68%	67%	69%
Sweden	39%	40%	42%	48%	38%	44%
Switzerland	33%	36%	35%	35%	35%	34%
France	14%	14%	13%	13%	12%	12%
Denmark	11%	9%	8%	7%	8%	9%
United States	6%	6%	6%	6%	6%	7%
Germany	3%	4%	5%	7%	11%	15%
Netherlands	1%	1%	2%	2%	2%	3%
UK	0%	1%	1%	1%	1%	2%

Source: IEA

Table 2. World leaders in existing Renewable energy capacity and production in 2006 and 2008

	TOP FIVE COUNTRIES				
	#1	#2	#3	#4	#5
2006					
Existing capacity					
Renewables power capacity	China	Germany	United States	Spain	India
Small hydro	China	Japan	United States	Italy	Brazil
Wind power	Germany	Spain/ United States		India	Denmark
Biomass power	United States	Brazil	Philippines	Germany/ Sweden/Finland	
Geothermal power	United States	Philippines	Mexico	Indonesia/Italy	
Solar PV (grid-connected)	Germany	Japan	United States	Spain	Netherlands/ Italy
Solar hot water	China	Turkey	Germany	Japan	Israel
Annual production					
Ethanol production	United States	Brazil	China	Germany	Spain
Biodiesel production	Germany	United States	France	Italy	Czech Republic
2008					
Existing capacity					
Renewables power capacity	China	United States	Germany	Spain	India
Small hydro	China	Japan	United States	Italy	Brazil
Wind power	United States	Germany	Spain	China	India
Biomass power	United States	Brazil	Philippines	Germany/Swede n /Finland	
Geothermal power	United States	Philippines	Indonesia	Mexico	Italy
Solar PV (grid-connected)	Germany	Spain	Japan	United States	South Korea
Solar hot water	China	Turkey	Germany	Japan	Israel

Annual production					
Ethanol production	United States	Brazil	China	France	Canada
Biodiesel production	Germany	United States	France	Argentina	Brazil

Note: Tables from REN21 (2007, 2009)

Table 3. CDM projects issued, registered and in pipeline in BRICS in May 2009

	Issued		Registered			Pipeline		
	% total projects	% total CER	% total projects	% total CER	% CER 2012	% total projects	% total CER	% CER 2012
Brazil	18%	11%	10%	7%	8%	8%	5%	6%
China	23%	44%	33%	58%	53%	37%	56%	54%
India	36%	23%	26%	12%	14%	26%	16%	16%
South Africa	1%	0%	1%	1%	1%	1%	1%	1%
% Total	78%	78%	70%	78%	76%	72%	78%	77%

Source: CDM website; Note: CER- certified emissions reduction

Table 4. Evolution of total number of CDM and JI projects in pipeline by BRICS

	2004	2005	2006	2007	2008	2009*	Total
Brazil	18	86	79	62	100	16	361
China	2	25	221	680	667	171	1766
India	11	198	268	304	375	95	1251
South Africa	1	6	9	7	4	2	29
Russia			12	43	37	7	99
Total CDM	60	473	837	1409	1561	393	4733
Total JI			23	84	84	13	204

* May 2009; Note: CER- certified emissions reduction

Table 5. Technological and Sectoral scope of total JI projects and JI hosted in Russia, May 2009

	% total JI projects	**% total CER**	**% JI projects hosted in Russia**
Fugitive	33%	46%	**33%**
EE (efficiency energy) supply side	11%	6%	2%
Biomass energy	10%	2%	**10%**
Fossil fuel switch	10%	5%	**10%**
Landfill gas	8%	5%	**8%**
N2O	7%	16%	**7%**
Energy distribution	5%	1%	5%
Hydro	4%	1%	4%
HFCs	3%	3%	3%
EE industry	2%	2%	**11%**
Coal bed/mine methane	2%	11%	2%
Biogas	1%	0%	1%
Cement	1%	1%	1%
CO2 capture	1%	1%	1%
PFCs	1%	1%	1%

Source: UNFCC (2009), JI (2009)

Table 6. Sectoral and technological scope of CDM projects, issued, registered and in the pipeline in Brazil, China, India and South Africa, in May 2009

	Brazil	**China**	**India**	**South Africa**	**World**		
	pipeline	**pipeline**	**pipeline**	**pipeline**	**issued**	**registered**	**Pipeline**
Hydro	21%	**47%**	**10%**	**7%**	19%	25%	27%
Biomass energy	**32%**	4%	27%	14%	21%	16%	15%
Wind	**3%**	19%	24%	**0%**	18%	14%	15%
EE own generation	3%	15%	10%	3%	6%	7%	9%
Landfill gas	11%	3%	2%	**21%**	7%	8%	8%
Biogas	2%	2%	3%	**10%**	1%	6%	6%
Agriculture	**16%**	0%	0%	0%	8%	8%	5%
EE industry	1%	1%	12%	3%	4%	3%	4%
Fossil fuel switch	5%	2%	4%	**14%**	4%	2%	3%
N2O	1%	2%	0%	**14%**	2%	3%	1%
Coal bed/mine methane	0%	4%	0%	7%	1%	1%	1%
EE supply side	1%	1%	2%	0%	1%	1%	1%
Cement	0%	0%	2%	0%	1%	1%	1%
Reforestation	1%	0%	1%	0%	0%	0%	1%
Fugitive	1%	0%	1%	3%	1%	1%	1%
Solar	0%	0%	0%	0%	0%	1%	1%
HFCs	0%	1%	1%	0%	3%	1%	0%

Geothermal	0%	0%	0%	0%	0%	0%	0%
EE households	0%	0%	0%	3%	0%	0%	0%
EE service	0%	0%	1%	0%	0%	0%	0%
Transport	0%	0%	0%	0%	0%	0%	0%
PFCs	1%	0%	0%	0%	0%	0%	0%
Energy distribution	1%	0%	0%	0%	0%	0%	0%
Afforestation	0%	0%	0%	0%	0%	0%	0%
CO2 capture	0%	0%	0%	0%	0%	0%	0%
Tidal	0%	0%	0%	0%	0%	0%	0%
Total	361	1766	1251	29	500	**1596**	**4733**

Source: UNFCC (2009), CDM (2009)

Table 7. Main buyers of CDM and JI projects in pipeline hosted by BRICS, in 2009

	CDM projects				JI projects
	Brazil	China	India*	South Africa	Russia
Austria	0%	3%	0.40%	0%	6%
Denmark	0%	1%	0%	4%	9%
Germany	2%	6%	3%	4%	0%
Japan	7%	15%	2%	4%	2%
Sweden	1.4%	10%	0.40%	0%	4%
Switzerland	21%	11%	6%	7%	2%
The Netherlands	10%	15%	2%	18%	5%
United Kingdom	28%	33%	13%	29%	25%
Total	69%	94%	27%	66%	53%

Source: UNFCC (2009), CDM (2009), JI (2009).

Note: In India, 75% of projects were proposed by international or national organisations.

Table 8. Participation of Japan, Netherlands, Switzerland and the UK in CDM projects in the most common scopes of CDM in pipeline in 2009, hosted by the BRICS

HOST	Technological SCOPE	N. Projects hosted	Japan	Netherlands	Switzerland	UK	These 4 countries on total projects*
Brazil	Agriculture	59	0%	0%	43%	40%	124%
	Biomass energy	114	27%	49%	19%	40%	69%
	Coal bed/mine methane	0	0%	0%	0%	0%	0%
	EE own generation	11	0%	0%	0%	0%	0%
	Fossil fuel switch	18	4%	0%	5%	4%	50%
	Hydro	76	38%	26%	15%	13%	57%
	Landfill gas	41	23%	14%	7%	1%	41%
	Wind	11	0%	0%	3%	1%	27%
	Total %	**91%**	**92%**	**89%**	**92%**	**99%**	
	Total projects	**361**	**26**	**35**	**74**	**102**	
China	Agriculture	1	0%	0%	0%	0%	100%
	Biomass energy	76	1%	3%	3%	8%	80%
	Coal bed/mine methane	63	4%	5%	4%	6%	103%
	EE own generation	257	13%	3%	19%	18%	72%
	Fossil fuel switch	32	2%	0%	2%	3%	78%
	Hydro	829	60%	65%	0%	30%	61%
	Landfill gas	56	2%	3%	4%	3%	66%

	Wind	337	7%	16%	20%	26%	74%
	Total %	**93%**	**89%**	**95%**	**51%**	**93%**	
	Total projects	**1766**	**260**	**273**	**194**	**580**	
India	Agriculture	3	0%	0%	0%	0%	0%
	Biomass energy	336	11%	30%	51%	41%	35%
	Coal bed/mine methane	0	0%	0%	0%	0%	0%
	EE own generation	123	4%	17%	18%	10%	29%
	Fossil fuel switch	51	0%	3%	0%	3%	12%
	Hydro	127	18%	17%	1%	9%	20%
	Landfill gas	26	0%	0%	1%	2%	15%
	Wind	298	39%	10%	10%	12%	14%
	Total %	**77%**	**71%**	**77%**	**81%**	**77%**	
	Total projects	**1251**	**28**	**30**	**73**	**165**	
South Africa	Agriculture	0	0%	0%	0%	0%	
	Biomass energy	4	0%	0%	0%	13%	25%
	Coal bed/mine methane	2	0%	0%	0%	0%	0%
	EE own generation	1	0%	0%	50%	0%	100%
	Fossil fuel switch	4	0%	20%	0%	0%	25%
	Hydro	2	0%	20%	0%	0%	50%
	Landfill gas	6	0%	20%	0%	25%	67%
	Wind	0	0%	0%	0%	0%	

	Total %	**66%**	**0%**	**60%**	**50%**	**38%**	
	Total projects	**29**	**1**	**5**	**2**	**8**	

Source: UNFCC (2009), CDM (2009)

* Number of projects in which each buyer country participated. Each buyer country may have participated in projects with partners from other buyers countries. Hence the share of total projects in which these buyers countries participate can sum more than 100%.

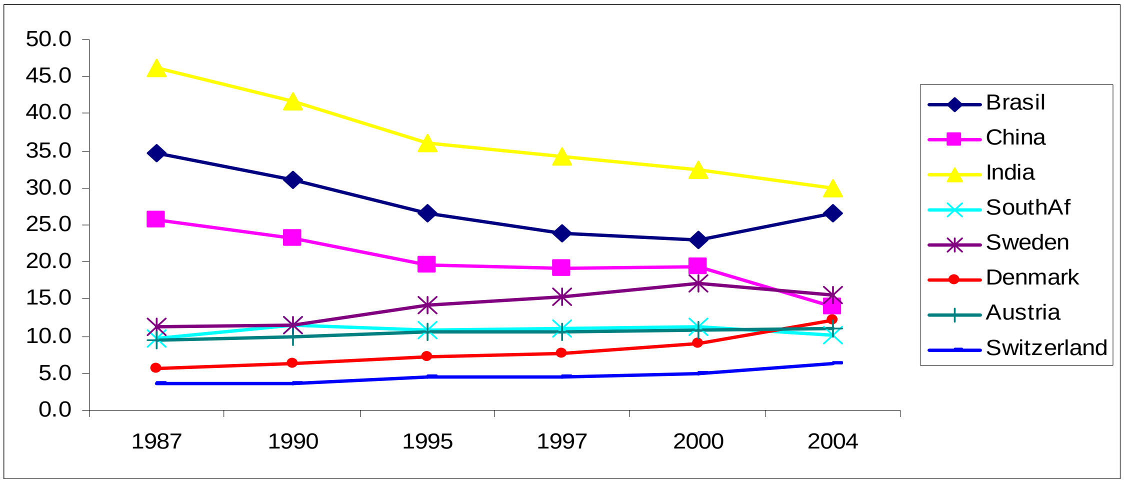
Table 8. Summary of correlation analysis on the different groups of factors affecting the diffusion of renewable energy technologies and on environmental performance of BRICS from 1987 to 2004

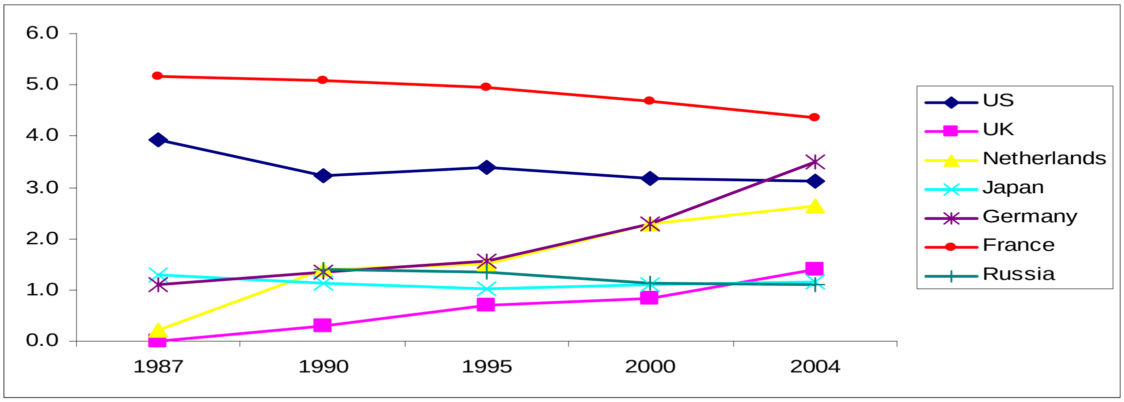
		GDP per unit of energy use (PPP $ per kg of oil equivalent)	% Combustible renewables and waste on total energy	% Renewable sources on total energy sources	% Fossil fuel energy consumption on total
National Natural endowments	Fossil resources	-	-	-	+
	Population (size and density)		+	+	-
	Water resources				-
	Forest resources			+	
National economic and Social Development	Literacy, Expenses per student, Health expenditures	-	-	-	
	GDP per capita	-	-	-	+
	Vehicles & computers		-	-	+
	Government debts	+			
	Growth GDP per capita		+		
	GDP industry	-	-	-	+
	GDP agriculture	-	+	+	-
	GDP services		-		
Internationalisation of national business	FDI, ISO certification				
	Export as import capacity; Royalties paid abroad % GDP		-	-	+
	Trademarks non residents		-		+
	Trademarks residents	+			
National technological capabilities	Expenses per student in tertiary education		+	+	
	% of Computer, communications and other services on	+	+	+	-

	services Secured servers				
	High-technology exports; R&D expenditures as % GDP; Patents residents per 1000 people; Researchers and technicians in R&D; Royalties received as % GDP; Scientific papers per 1000 people	-	-	-	+
National policy culture	Investment in energy with privates % GDP				
	National protected areas	+		+	-
	Military expenditures % GDP	-	-	-	+
Global institutional frameworks	Number of CDM and JI projects*	+			-
	CER registered*				

* 13 to 15 observations rather than 85 to 90 observations as for the other variables.

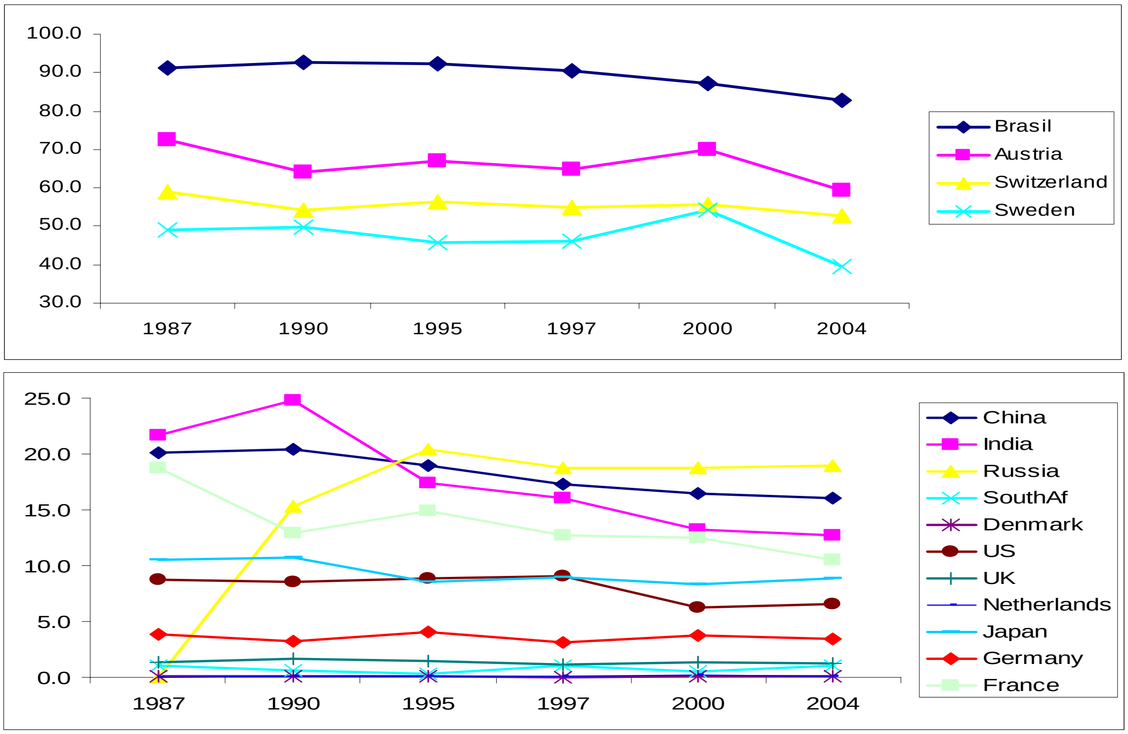
Graph 1: Share of combustible renewable and waste on total energy, in the BRICS and some developed countries, 1987 to 2004





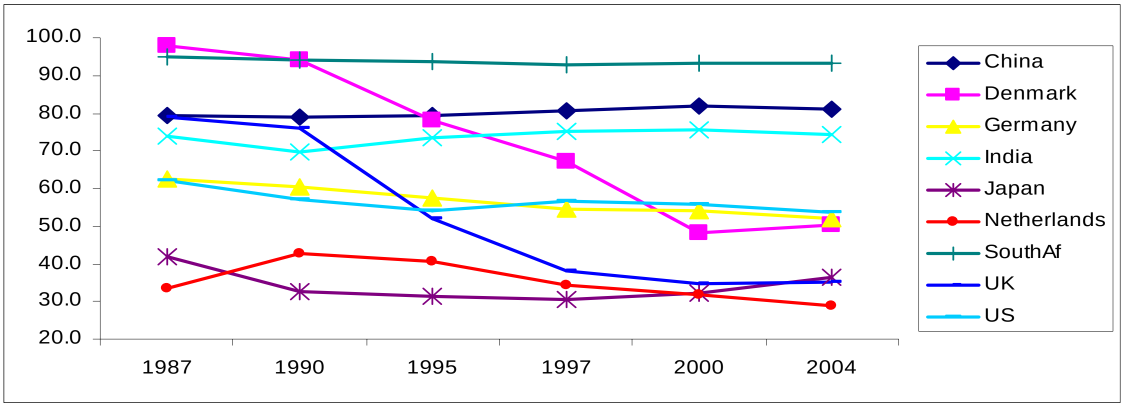
Source: World Bank Indicators. Note: Combustible renewables and waste comprise solid biomass, liquid biomass, biogas, industrial waste, and municipal waste, measured as a percentage of total energy use.

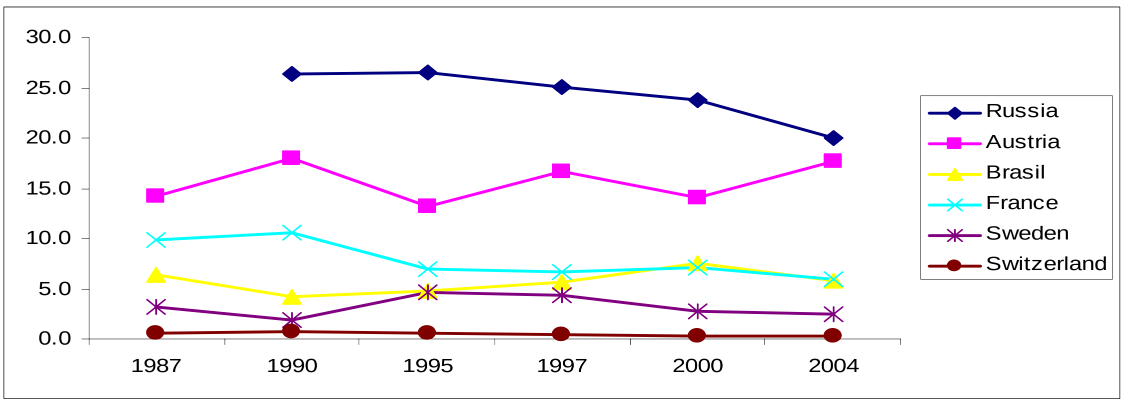
Graph 2. Electricity production from hydroelectric sources, in the BRICS and some developed countries, 1987 to 2004



Source: World Bank Indicators

Graph 3. Electricity production from coal and oil sources (% of total), in the BRICS and some developed countries, 1987 to 2004





Source: World Bank Indicators

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